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**MULTIPLE LINK INTERNET PROTOCOL MOBILE COMMUNICATIONS
SYSTEM AND METHOD THEREFOR**

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Technical Field

The present invention relates generally to a mobile communication system and, more particularly, to a communication system that uses multiple links for effectively communicating with a mobile user.

Background Art

5 In this communication age, content providers are increasingly investigating ways in which to provide more content to users as well as interfacing with users.

Communication satellites have become commonplace for use in many types of communication services, e.g., data transfer, voice communications, television spot beam coverage, and other data transfer
10 applications. In particular, data transfer may include coupling to the Internet to take advantage of the various resources provided therethrough.

One problem associated with providing mobile communications is maintaining a communications link between the moving mobile terminal and the high altitude device associated therewith. Many types of high altitude
15 devices are used in mobile communication systems including stratospheric platforms, middle earth orbit satellites and low earth orbit satellites. The satellites move relative to the earth and the mobile terminals also move relative to the earth. Prior known systems typically do not provide reliable links particularly in high data intensive applications.

20 For example, in such systems a single dynamic link may degrade over time due to the relative movement of the mobile terminal relative to the high altitude communication device. As the devices move, the quality of the link drops. Therefore, the total throughput of the system is inhibited.

It would therefore be desirable to provide a reliable mobile communication system capable of handling high data rates and doing so without sacrificing connectivity or data rate.

Summary of the Invention

It is therefore an object of the invention to provide a mobile
5 communication system that allows high data rate connectivity to the Internet.

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In one aspect of the invention, a communication system has high altitude devices that are coupled to user terminals through a plurality of dynamic links. The terminal monitors and changes the multiple dynamic links as the position of the user terminal relative to the high altitude devices changes.
10 The gateway terminal transmits and receives to said user terminals through the high altitude devices using a plurality of datagrams.

In a further aspect of the invention, a method for operating a communication system comprises the steps of:

forming a plurality of multiple communication links directed to a
15 plurality of high altitude communication devices;
dividing a communication into a plurality of datagrams;
routing the plurality of datagrams through the plurality of multiple communication links;
directing the datagrams from the high altitude communication
20 device to a gateway station; and
reassembling the datagrams into the communication.

One advantage of the invention is that a stratospheric platform may be used to provide the high altitude communication function. This allows

the communication system according to the present invention to be rapidly deployed.

Other objects and features of the present invention will become apparent when viewed in light of the detailed description of the preferred embodiment when taken in conjunction with the attached drawings and
 5 appended claims.

Brief Description of the Drawings

Figure 1 is a system diagram of a communication system according to the present invention.

Figure 2 is a suitable low profile antenna array for use in the
 10 present invention.

Figure 3 is a perspective view of a portable personal computer having an antenna array of Figure 2.

Figure 4 is a block diagrammatic view of a mobile satellite terminal in receive mode.

Figure 5 is a block diagrammatic view of a terminal in transmit
 15 mode.

Figure 6 is an alternative block diagrammatic view of a terminal in transmit mode.

~~INS AB~~
 20 ~~Figures 7A, 7B and 7C are flow diagrammatic view for receiving datagrams according to the present invention.~~

~~INS AH~~
~~Figure 8 is a organizational view of software implementation of the present invention.~~

Best Modes For Carrying Out The Invention

In the following description, the same reference numerals are used to identify the same components in the various views. Those skilled in the art will recognize that various other embodiments, structural changes and changes in measures may be made without departing from the scope of the invention. The following description is described with respect to mobile terminals. Although the advantages are evident in mobile applications, the present invention could be used for fixed terminals.

Referring now to Figure 1, a communications system 10 is used to couple plurality of user terminals 16M and 16F with a plurality of high altitude communications devices 18A, 18B and 18C and will be collectively be referred to as high altitude communication device 18. A plurality of user terminals 16M and 16F are used to illustrate mobile users and fixed users, respectively. Mobile users 16M may comprise but are not limited to automotive applications and other types of transportation systems such airplanes, trains, ships, personal digital assistant applications, portable computers and cellular phone applications. Fixed user terminals 16F may, for example, comprise business-based or consumer-based communication systems. Each user terminal 16F and 16M may receive a signal with the predetermined signal strength from a spot beam pattern that is radiated from each high altitude communication device 18. The present invention is particularly advantageous for use with mobile terminals 16M.

Communication system 10 further includes a gateway station 20 that is coupled to terrestrial networks 22. Communication system may also include a platform operations center 24. Both gateway station 20 and platform operations center 24 are in communication with stratospheric platform 18. Gateway station 20 provides a link between user terminals 16F, 16M and

terrestrial networks 22 through stratospheric platforms 18. Platform operation center 24 provides command and control functions to communications platform 18. Although illustrated as two separate units, gateway station 20 and platform operation center 24 may be combined into the same physical location.

5 The communication signals between stratospheric platform 18 and user terminals 16M and 16F may be referred to as user links 26. User links 26 represent the transmit and receive beams from both categories of user terminals 16F, 16M and high altitude communications platform 18. A feeder link 28 is defined between high altitude communications platform 18 and
10 gateway station 20.

 High altitude communications platform 18 may be a stratosphere-based platform. Stratospheric based platforms may be implemented in many forms including an unmanned vehicle that can fly for several months at an altitude of over 60,000 feet above the earth. The
15 stratospheric platform is operated through the platform operations center 24 to fly in a small radius flight path over a given spot on the earth. As far as users are concerned, the platform is geo-stationary. In addition to a plane-like platform, the stratospheric platform may comprise a balloon or blimp-like platforms. Communications platforms 18 may also be formed from
20 geostationary (GEO), middle earth orbit (MEO) or low earth orbit (LEO) satellites. It is more likely that the system be implemented in LEO or MEO satellites, if satellites are used.

INSAS > ~~Communications platforms 18 are used as a communication node for gateway station 20 and user terminals 16F and 16M. Gateway station 20 has
25 antennas 21A, 21B and 21C corresponding to a respective one of the high altitude communications platforms 18A, 18B and 18C. As will be described below, the pointing from mobile terminals 16M may be performed~~

electronically. Although only one gateway station 20 is illustrated in the figure, those skilled in the art would recognize that various numbers of interconnected gateway stations 20 may be employed. As would be further described below, gateway station 20 with high gain antenna 21A, 21B 21C that has a narrow beam width. The antenna may need a tracking mechanism with tracking speed adequate enough to maintain a communication link with the platform 18 throughout the flight path. Gateway station 20 may be coupled to a gateway control circuit 22 which is ultimately connected to the Internet 24, or a corporate intranet.

Each high altitude communication platform 18 has a respective payload 30A, 30B and 30C that links with user terminal 16M, 16F through the use of a phased array antenna and gateway station 20 with a feeder link antenna (preferably a parabolic dish) described below. In the present example, the payload 30 is used to generate a plurality of user beams configured according to the signals as determined in the gateway station 20.

Gateway control circuit 22 may have various circuitry coupled thereto. For example, analog or digital TV 32, an up converter 34, and a cable modem terminal shelf (CMTS) 36. CMTS may be used to couple to Internet 24. CMTS 36 may be coupled to a hub 38 that has various resources coupled thereto. The hub 38 may, for example, have a management server 40, a world wide web, e-mail or news server 42 or a proxy server 44.

Referring now to Figure 2, an antenna 46 for use with the present invention is illustrated. Antenna 46 is preferably a patch antenna having a plurality of elements 48. The patch antenna is capable of simultaneously generating multiple links to the various high altitude communication devices 18. Various size and shape antennas are contemplated depending on the specific application. Such an antenna provides the advantages of being low cost, low

profile, and high in performance which will encourage adoption in the consumer market. As illustrated in Figure 3, antenna may, for example, be approximately 12" x 18" with 12 elements 48. Each element may, for example, be 0.3 wavelengths in diameter. Each of the elements may, for example, be placed

5 0.45 wavelengths apart in the rectangular lattice. Therefore, the total aperture is a square of about 2 wavelengths x 1.5 wavelengths. The expected peak gain in such a system is 14 dB at the boresite, and 12 dB at 60 degrees away from the boresite. The beam widths for the boresite elliptical beam may be approximately 30 degrees and approximately 35 degrees, respectively. The

10 elements are dielectrically loaded and properly matched to have an element beam width of about 150 degrees. Overall aperture efficiency is over 80 percent due to the densely populated elements. It is envisioned that in a consumer application, a motherboard having a number of identical elements may be used. Antenna 46 converts the received microwave power into a digital stream in the

15 receiving direction and converts the digital stream into radiated power in the transmitting direction. The phasing of the elements is implemented by digital multiplication on the motherboard as will be further described below. Performance-wise, a maximum bandwidth for a user signal is assumed to be about 5 MHz. A sampling rate such as approximately 100 Msps with an

20 approximately 4 bit resolution may be used. An aperture time of the analog-to-digital converter may be less than one-eighth of the period of the carrier frequency. At a 2 GHz carrier frequency, for example, an aperture time of 50 picoseconds is adequate.

Such a design is preferably scalable to allow other elements 48 to

25 be plugged into the array. Such flexibility allows higher gain for the antenna 46, if needed.

When forming multiple beams or links, the sampled signals at element level will be "reused" for the second, third and rest of the beams. As

will be further described below, different sets of digital beam formers and frequency and time circuitry are used. Therefore, the incremental cost and processing load of additional beams is low. When first activated, antenna 46 during an acquisition phase all beams will be used simultaneously over the entire field of view of a fan-beam. Thus, the search volume will be reduced to a one-dimensional search in time sequence. If some knowledge is present in the system, only a few beams may be needed to establish the link acquisition.

When a user link is established, the beam generated by a user terminal may be electronically tracked to match that of the movement of platforms. Signal strengths from adjacent beams are monitored and compared to the main beam. The beam with the strongest signal will be identified and locked as the main beam. As the platform and/or user moves, the main beam may be switched. The terminal will always choose the beam with the strongest (desired) received signal as the main beam.

Referring now to Figure 3, a portable personal computer having an antenna 46 formed according to Figure 2 is illustrated. Because of the relatively small, thin profile of the antenna, incorporation into a portable personal computer is relatively easy.

Referring now to Figure 4, a user terminal 52 is illustrated in block diagrammatic form. User terminal 52 generally has a digital beam forming network 54 coupled to a demodulator 56. Demodulator 56 is coupled to a hub and router circuit 58. A direction control circuit 60 is coupled to hub and router circuit 58 and to digital beam forming circuit 54. The general operation of user terminal 52 is that multiple beams are generated at digital beam forming circuit 54. Direction control circuit 60 generally tracks the direction of the movement of the user terminal 52 and the high altitude devices

and provides this information to hub and router circuit 58 and the digital beam forming circuit 54.

Digital beam forming circuit 54 has a plurality of elements 62 that correspond to the elements 48 shown in Figure 2. Various groupings of elements 62 are used to generate the simultaneous multiple links of the present invention. Each element 62 is coupled to a corresponding analog-to-digital converter 64 through a band pass filter (BPF) 63. The digital outputs from all analog-to-digital converters 64 are weighted and summed, and then grouped together to form beams beam 1 through beam m as illustrated. The beams are formed by numerical multiplications using the direction vector beam 1 illustrated as reference numeral 66 and through direction vector beam m through forming circuit 70. Forming circuit 70 may have a plurality of multiplication blocks 72 and summing blocks 74 implemented either physically or in software to form the various beams. Functions of beam forming, frequency tuning and time synchronization are interlaced to minimize the over-processing mode, instead of sequentially. This approach eliminates conventional phase shifters and minimizes the required RF components making the implementation suitable for consumer applications. Digital beam forming circuit 54 will typically be used to generate multiple simultaneous links with high altitude device 18. It is envisioned that about no more than 10 multiple links would be established at any time.

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The links or beams are coupled to a demodulator 56 which demodulates signals and recovers the information in various package or datagrams. The recovered information are provided to routing circuit 58 which has a hub and router circuit 76 coupled to a routing table 78 which is updated from direction control circuit 60. Hub and router circuit 76 is coupled to a transport circuit 80 which in turn is coupled to an applications circuit 82. As will be further described below, each user link has only a portion of the total

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5 signal to be received. These signal portions are referred to as datagrams in the present invention. Hub and router 76 receive various datagrams from the different user links 76 and reassembles them. The various datagrams may not arrive in a sequential order. Thus, hub and router 76 assembles them and may have to shuffle the datagram packets to provide the desired reassembled signal. Once receiving an entire communication segment, transport circuit 80 couples the signal to various applications within the device such as a web browser or other programs. It should be noted that the fragments must all be reassembled in order to provide a coherent message. If any of the fragments are lost, the

10 transport layer will order a retransmit of the missing portion of the datagram. The terminal may start a reassembly timer when it receives an initial fragment. If the timer expires before all the fragments arrive, the user terminal 52 may discard the surviving pieces without processing the datagram. A request for resending the signal may be initiated.

15 Direction control circuit 60 is coupled to external calibrations 84 which may be input to the system. External calibrations may include information about the various satellites in the system and the relative positions thereof. Estimation algorithms 86 are coupled to external calibrations 84. Estimation algorithms 86 determine a user state vector 88 and a platform state

20 vector 90. The user state vector 88 and platform state vectors 90 determined the absolute position of each of the high altitude devices and of the user. The user state vector 88 and the platform state vectors 90 are used to generate relative position vectors 92 between user state vector 88 and platform state vectors 90. The relative position vectors 92 are used to generate motion vector correction

25 factor 94 which in turn are provided to routing table 78 in hub and router circuit 58 so the directions of the links (or direction of array beams) can be changed.

Referring now to Figure 5, a transmit circuit similar to that shown in Figure 4 is illustrated with the same reference numerals illustrated

above. It is a generic diagram in which only one modulation is associated with an array beam. It is possible to have multiple links through different beams and different modulation. In the digital beam forming for a given beam, the signal is divided, phase-weighted, and individually modulated before summing circuits
 5 for all the elements. The modulation is performed in the microwave carrier frequency by a modulator 96 in every element for each beam. Every element will group all the modulated signals from various beams together before amplification. The amplified element signals are radiated to far field. As a result of the proper phasing in digital beam forming, signals designated for a beam
 10 direction radiated from various elements will be coherently summed together in the far field at the particular direction. Similarly signals for the second beam direction will also be spatially combined coherently in the corresponding directions. The modulations for the first and second beams may not be the same.

The difference between the transmit architectures in Figure 5 and
 15 Figure 6 is how the modulation is performed. In Figure 5, the modulation processing is performed in RF frequency band while that in Figure 6 the transmit signals are modulated in base-band. In Figure 6, a circuit similar to that of Figure 4 is illustrated. In this figure, the modulator 96' has been moved in front of the digital beam forming circuit 54 , connecting hub and router
 20 circuit 58 and digital beam forming circuit 54. This configuration is believed to be advantageous for a multiple beam configuration.

In operation, the present invention preferably uses TCP/IP protocol. The TCP/IP protocol allows the user terminal to generate both multiple and receiving and transmitting beams to take advantage of the different
 25 high altitude communication devices in view to transmit and receive various datagrams, which are portions of complete messages, to and from the gateway terminal. The gateway terminal also receives the datagrams and reassembles them. The present invention takes advantage of the existing TCP/IP protocol

and applies it to multi-beam mobile applications. This combination allows mobile terminals to operate in packet-by-packet modes efficiently rather than circuit designated modes, taking advantage of high dynamics from multiple beams and providing various bundled multimedia mobile services to various content providers from TCP/IP protocol.

Referring now to Figure 8, the TCP/IP protocol is constructed by layers of modular protocol software. Each layer of the software handles a portion of the problem. For example, one layer of the receive terminal must decide whether to keep the message or forward it to another machine. Another layer must decide which application program should receive the message. Table 98 shows a software organization 102 in various conceptual layers, similar to the Open System Interconnection (OSI) layers. Conceptual layers have a network interface layer 108 (or physical and link layers in the OSI layer structure), an Internet protocol layer 106 (or a network layer), and a high level protocol layer 104. In the high level layer 104 we have grouped all other OSI layers together; from transport, session, presentation and applications. Various protocols 110A, 110B, and 110C are illustrated coupled to an IP module 112. The IP module 112 is coupled to an interface 114A, 114B, and 114C. The protocols correspond to high level protocol layer 104, IP module 112 corresponds to Internet protocol layer 106, and interfaces 114A, B and C correspond to network interface layer 108. Thus as shown, the IP software may communicate with multiple high level protocol modules with multiple network interfaces. From table 98 it is clear that IP protocol is the protocol in the network layer. The IP protocol software must interface with multiple protocols below IP and the IP protocol software must also work with multiple protocols above IP. Preferably, each interface below IP is a wireless link using open communication architecture to set up the terminal software modules cost effectively.

In a receive mode, an aggregated data stream intended for a user terminal is grouped into datagrams which are the basic transfer units in the TCP/IP protocol. A datagram is divided into a header and a data area. The IP protocol specifies the header format including the source and destination IP address. The IP protocol does not specify the format of the data area. Arbitrary data may be transmitted in the data area. The length of the datagram is given by the total field length which is specified as 16 bits long. Therefore, the maximum of the datagram is 64 kilobytes.

The TCP/IP software chooses a convenient initial datagram size for the communication and arranges a way to divide large datagrams into smaller pieces when the datagram needs to traverse a network that has a small maximum transfer unit (MTU). The small pieces or communication portions into which a datagram is divided are called fragments, and the process of dividing a datagram is known as fragmentation. Fragmentation usually occurs at a router somewhere along the path between the datagram source and its ultimate destination. The router receives a datagram from a network with a large MTU and must send it over a network for which the MTU is smaller than the datagram size. Once the datagram has been fragmented, the fragments travel as separate datagrams all the way to the ultimate destination where they are reassembled. In the present case, each of the datagrams may be sent to the high altitude device 18 through multiple links from user terminal 52. The datagrams are then sent through multiple links from the high altitude devices 18 to a gateway station where they are reassembled. The datagrams are reassembled before any demultiplexing processes by arranging the fragments received from the various links. If any fragments are lost, the datagram cannot be reassembled. The terminal may start a reassembly timer when it receives an initial fragment. If the timer expires before all the fragments arrive, the user terminal may discard the surviving pieces without processing the datagram. At

a high layer of the TCP protocol, a re-send signal may be sent for the entire datagram.

Referring now to Figures 7A, 7B, and 7C, three levels of multiplexing are indicated. In Figure 7A, the first demultiplexing is at incoming frame where frame arrives in block 116. In block 118, the demultiplexing is based upon the frame type. The frame content following the header may be an IP module 120, an address resolution protocol (ARP) module 122, or a reverse address resolution module (RARP) 124. In Figure 7B, a datagram arrives in block 126, the resident IP software chooses an appropriate receiver to handle the datagram based on the protocol type field in the datagram header in block 128. Datagram may be classified according to various protocols such as Internet control message protocol (ICMP) 130, for router and host to send reports of problems of the datagrams to the originator including echo requests and replies, User Datagram Protocol (UDP protocol) 132 which is connection oriented, TCP protocol 134 which is connection oriented, and exterior gateway protocol (EGP) 136 for a router in one autonomous system, advertise the IP address of the networks in that autonomous system to a router in another autonomous system.

Referring now to Figure 7C, the third demultiplexing may take place at a level higher than the IP layer 138. In this example, UDP 140 uses a UDP destination port number to select the appropriate destination port for incoming datagrams. A socket uniquely requests an IP plus a port number. As illustrated, three ports 142, 144, and 146 are illustrated connected to UDP 140. Connection between two hosts are specified fully by sockets assigned to each connection end. Connections between two sockets are full dual duplex communication paths between end processes. TCP uses connection, not protocol port as its fundamental abstraction; connections identified by a pair of

The first two terms on the right-hand side of (1) are the
 \mathcal{L}_2 norm of the function f and its gradient, respectively.
 The third term is the \mathcal{L}_2 norm of the function f and its
 gradient, weighted by the weight function w .

While the best modes for carrying out the invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.